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THE PROBLEMS OF COUNTERACTING ARM SYSTEM DESIGN

by

Shen Yunchun

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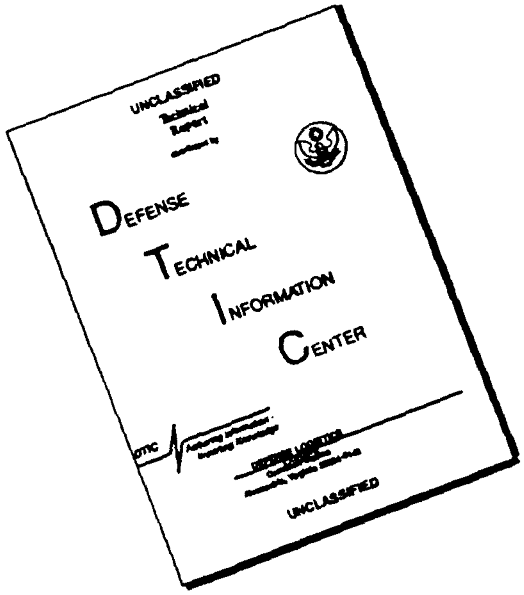

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THE PROBLEMS OF COUNTERACTING ARM SYSTEM DESIGN

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ABSTRACT

Anti-radiation missiles (ARM) have become serious threats to military radar. It is an extremely important and complicated research task for counteracting ARM. The problems of counteracting ARM system design are discussed in this paper. It is extremely important to discover ARM and give warning as early as possible. The dynamic range of a warning receiver should satisfy such requirement -- $D_1 \geq \sqrt{\sigma_1/\sigma_2}\cdot\sigma_1$ -- radar section of a plane, σ_2 -- radar section area of ARM. This paper has also analyzed the effect of two interference sources. Both the coherent interferences and incoherent interferences could cause the angle deviation of radar homing head of ARM. The formulas of angle deviation which could be caused by the interferences are given in this paper. How to set the interference sources is also discussed.
Key words: ew, eccm, radar, missile, ~~anti-radar missile~~ or anti-radiation missile. [Transcribed verbatim from original article]

1. FOREWORD

Since the 1960's, when the United States first used the Lark anti-radiation missile on the Vietnam battlefield, the U.S. s anti-radiation missiles, after incessant improvements and new development, have come to their third generation (the second generation was the Standard anti-radiation missile, and the third generation is the HARM anti-radiation missile), Currently, in addition to the U.S., Great Britain, France, the Soviet Union, West Germany, Sweden, Norway and Israel have at their disposal anti-radiation missiles which they have developed themselves. On the battlefield of Vietnam, in the Mid-East conflict, the attacks of Syria and Israel on Lebanon, and in the 1985 conflict between the U.S. and Libya, anti-radiation missiles were used effectively. In actual combat, anti-radiation missiles are able to suppress enemy electromagnetic radiation sources; they are a hard antipersonnel weapon with an outstanding performance, and compose a serious threat to military radar. The study of how to combat anti-radiation missiles has already become a very important field of study. This paper gives a concise discussion of several important problems in the study of countering anti-radiation missiles.

2. SEVERAL PROBLEMS IN THE RESEARCH ON COUNTERING ANTI-RADIATION MISSILES

A. The Problem of Anti-Radiation Missile Attack Warning

Increasing missile speed has become one developmental direction in the area of countering anti-radiation missiles. The U.S.' HARM missiles have a speed that reaches 3 mach. In this way, the response time available to the anti-anti-radiation systems is very short. In order to defend against anti-radiation missiles, it is a precondition to detect the raiding anti-radiation missiles extremely early. However, the effective section area of the carrier, at the very least, is several dozen times larger than the effective section area of the anti-radiation missile; if the anti-radiation missile employs concealment technology, the ratio between the two effective section areas will be even greater. Normally, the "dynamic range of the receiver" indicates the dynamic range within the whole radar operational distance. For this reason, after a carrier has released its missile, because the carrier's effective section area is much larger than the missile's effective section area, on the display of most radar systems the return wave of the missile will not be visible. Receivers used for issuing warnings on attacking anti-radiation missiles, in addition to having to fulfill the requirements for a normal radar receiver dynamic range, must also possess a sufficient instantaneous dynamic range; further, they must have sufficient signal amplitude compression capability, so that the range of variations in the receiver's output signal amplitude matches the dynamic range permitted by the radar terminal.

Assume that the carrier's effective surface area is σ_1 and the effective section area of the anti-radiation missile is σ_2. The dynamic range allowed by the radar terminal is D_2; the instantaneous dynamic range of the receiver ought to fulfill:

$$D_1 \geq \sqrt{\sigma_1/\sigma_2} \quad (1)$$

The compression coefficient k of the receiver with respect to the signal amplitude is:

$$k = D_1/D_2 \quad (2)$$

Currently existing anti-radiation missiles are able to undertake attack from the radar's parasitic lobe and rear lobe. Tracking radar finds it difficult to fulfill the requirement of sounding out anti-radiation missiles attacking from the parasitic lobe or the rear lobe. As regards search radar with circumference searching, to perform the task of warning, the search circumference T must satisfy the condition $T < t_1 - t_2$, where t_1 is the flight time of the missile and t_2 is the reaction time of the anti-anti-radiation missile system. When the anti-radiation missile's speed is relatively great or the distance of the launch is rather small, with the result that t_1 is small or the anti-anti-radiation missile system's reaction time t_2 is relatively large, the search radar will be hard put to satisfy the requirements of circumference search. One way of solving the problem of reliable warning is to install a special warning radar. This kind of radar takes advantage of the characteristic of the anti-radiation missile flying toward the radar station with a relatively great radial speed. It can use the PD system and take advantage of many antennas to form a wave beam covering a semispherical air space, in order to probe rapidly and in all directions for attacking anti-radiation missiles. As regards the design of the warning installation, there are many specialized questions which must be discussed; owing to limitations in space, this article cannot handle them in detail.

B. Using Coherent or Incoherent Point Sources to Undertake Deflection

The radar guidance head of foreign anti-radiation missiles often uses the single pulse system; for this reason, the use of double location sources or multiple location sources to undertake interference is an effective countermeasure. This paper will briefly analyze this problem.

Assume that the radar guidance head of the anti-radiation missile employs the oscillation amplitude and different unit pulse system, that the antenna direction image function is F(θ), that the differential wave beam angle of separation is $2\theta_0$, that the first source corresponds to the antenna electrical axis angle of deviation of θ_1 and the second source corresponds to the antenna electrical axis angle of deviation of θ_2. The distance between the two sources is L. In this way, the phase centers of the two sources are not together. When a missile flies toward the radar station, it immediately causes the two sources to perform strict frequency and phase locking on the missile in its motion, unless the missile is moving along the vertical half-plane of the line joining the two sources; if not, the electrical wave emitted by these two sources will change constantly when they reach the relative phase of the missile location. For this reason, it is reasonable to assume that the relative phase difference of the electrical waves of these two sources reaching the location of the missile is φ, and that φ is a random quantity evenly distributed between $(0 \sim 2\pi)$ In order to simplify analysis, assume that the receiving system is an ideal system without distortion.

For two coherent sources the aggregate differences are respectively:

$$s_s(t,\theta)=U_{m1}(F(\theta_0-\theta_1)+F(\theta_0+\theta_1))e^{j\omega t}+U_{m2}(F(\theta_0-\theta_2)+F(\theta_0+\theta_2))e^{j(\omega t+\varphi)} \tag{3}$$

$$s_d(t,\theta)=U_{m1}(F(\theta_0-\theta_1)-F(\theta_0+\theta_1))e^{j\omega t}+U_{m2}(F(\theta_0-\theta_2)-F(\theta_0+\theta_2))e^{j(\omega t+\varphi)} \tag{4}$$

For two incoherent sources the aggregate difference are respectively:

$$s_s(t,\theta)=U_{m1}(F(\theta_0-\theta_1)+F(\theta_0+\theta_1))e^{j\omega_1 t}+U_{m2}(F(\theta_0-\theta_2)+F(\theta_0+\theta_2)) e^{j(\omega_2 t+\varphi)} \tag{5}$$

$$s_d(t,\theta)=U_{m2}(F(\theta_0-\theta_1)-F(\theta_0+\theta_1))e^{j\omega_1 t}+U_{m2}(F(\theta_0-\theta_2)-F(\theta_0+\theta_2)) e^{j(\omega_2 t+\varphi)} \tag{6}$$

Assume the phase detector completes its calculations as follows:

$$u_{s,d}=\frac{R_e[s_s(t,\theta)s_d^*(t,\theta)]}{s_s(t,\theta)s_s^*(t,\theta)} \tag{7}$$

In the formula, * indicates conjugations. Let:

$$\beta=U_{m1}/U_{m2} \tag{8}$$

After calculations, we obtain that at the two coherent sources:

$$u_{pd} = \frac{\beta^2(F^2(\theta_0-\theta_1)-F^2(\theta_0+\theta_1))+(F^2(\theta_0-\theta_2)-F^2(\theta_0+\theta_2))+2\beta}{\beta^2(F(\theta_0-\theta_1)+F(\theta_0+\theta_1))^2+((\theta_0-\theta_2)+F(\theta_0+\theta_2))^2+2\beta}$$

$$\frac{\cos\varphi(F(\theta_0-\theta_1)F(\theta_0-\theta_2)-F(\theta_0+\theta_1)F(\theta_0+\theta_2))}{\cos\varphi(F(\theta_0-\theta_1)+F(\theta_0+\theta_1))(F(\theta_0-\theta_2)+F(\theta_0+\theta_2))} \qquad (9)$$

Regarding the two incoherent sources:

$$u_{pd} = \frac{\beta^2(F^2(\theta_0-\theta_1)-F^2(\theta_0+\theta_1))+(F^2(\theta_0-\theta_2)-F^2(\theta_0+\theta_2))+2\beta\cos(\Omega_b t}{\beta^2(F(\theta_0-\theta_1)+F(\theta_0+\theta_1))^2+(F(\theta_0-\theta_2)+F(\theta_0+\theta_2))^2+2\beta\cos(\Omega_b t-\varphi)(F}$$

$$\frac{-\varphi)(F(\theta_0-\theta_1)F(\theta_0-\theta_2)-F(\theta_0+\theta_1)F(\theta_0+\theta_2))}{(\theta_0-\theta_1)F(\theta_0-\theta_2)+F(\theta_0-\theta_1)F(\theta_0+\theta_2)+F(\theta_0+\theta_1)F(\theta_0-\theta_2)+F(\theta_0+\theta_1)F(\theta_0+\theta_2))} \qquad (10)$$

In the formula, $\Omega_b = \omega_1 - \omega_2$

The equilibrium point of the antenna is determined by $u_{pd}=0$, that is $R_e(\dot{u}_s \dot{u}_d^*) = 0$. Regarding the coherent two point source, it is determined from the following formula:

$$\beta^2(F^2(\theta_0-\theta_1)-F^2(\theta_0+\theta_1))+(F^2(\theta_0-\theta_2)-F^2(\theta_0+\theta_2))+2\beta\cos\varphi(F(\theta_0-\theta_1)F(\theta_0-\theta_2)-F(\theta_0+\theta_1)F(\theta_0+\theta_2))=0 \qquad (11)$$

Regarding the incoherent two point source, ω_1 and ω_2 cannot be too far apart; it is necessary to cause them both to be located within the bandpass of the guidance head receiver; even so, Ω_b normally also has several MHz. In this way, regarding the coherent two-point source, the central frequency of u_{pd} is Ω_b, and its high order quantity will not be able to pass through the phase detector and the low filter of the AGC wave detector. For this reason, regarding the incoherent two-point source, the antenna equilibrium point will be determined by the following formula:

$$\beta^2(F^2(\theta_0-\theta_1)-F^2(\theta_0+\theta_1))+(F^2(\theta_0-\theta_2)-F^2(\theta_0+\theta_2))=0 \qquad (12)$$

When the electrical axis deviation of the two sources with respect to the guidance head antenna is not great, we may approximate as follows:

$$F(\theta_0 \pm \theta) \approx F(\theta_0)(1 \mp \mu\theta) \qquad (13)$$

Here, μ is a constant. Again, make $\theta_2 = \theta_1$, $\theta_1 = \theta - \Delta\theta$. In this way, $\Delta\theta$ represents the divergent angle of the two point source with respect to the guidance head. Substituting these relations into formulas (11) and (12), we obtain, for the coherent source:

$$\theta = \frac{\Delta\theta\beta(\beta + \cos\varphi)}{1 + 2\beta\cos\varphi + \beta^2} \qquad (14)$$

When φ is evenly distributed within the range of $(0 \sim 2\pi)$ the mean value of θ is:

$$\bar{\theta} = \frac{1}{2\pi}\int_{-\pi}^{\pi} \frac{\Delta\theta\beta(\beta + \cos\varphi)}{1 + 2\beta\cos\varphi + \beta^2} d\varphi = \begin{cases} \Delta\theta & \beta > 1 \\ \frac{\Delta\theta}{2} & \beta = 1 \\ 0 & \beta < 1 \end{cases} \qquad (15)$$

From this it can be seen that, under conditions of a coherent two-point source, as long as the radiation power of the interference source is maintained at a higher level than that of the radar that is being protected, it is possible to direct the missile toward the source of the interference.

Regarding the incoherent two-point source, after merging formula (13) into (12), we can solve as follows:

$$\theta = \frac{\Delta\theta\beta^2}{1 + \beta^2} \qquad (16)$$

From the above formula it can be seen that under conditions of an incoherent two-point source, the electrical axis of the guidance head antenna will point toward the energy center of the two sources.

C. Choosing the Two-Point Source Amplitude Ratio β and Distance L

It can be seen from formula (15) and (16) that when β=1, that is, when the two-point source's power is equivalent, the guidance head electrical axis will point toward the center of the line linking the two points. To guarantee that the radar station not suffer damage, it is helpful to make the power of the interference source slightly larger than the power of the radar.

In order to obtain the formula showing the distance between the two points, as a reference for engineering design, we will begin our discussion from a simplified set of circumstances. Assume the missile and the two-point source are located on the same plane, that the missile is flying along the vertical bisector of the line linking the two point sources, and that it is flying at a velocity of v; when it reaches point A in Fig. 1, the angle of divergence of the guidance head with respect to the two sources is the guidance head antenna split angle θ_c. Beginning at point A, the missile moves with the maximum overload η; its landing point is C. Below, we solve for the maximum deviation $|O_2C|_{max}$ of the missile with respect to O_2. Because we are only considering the conditions during a very short time before the landing point the missile's speed at this time is very great, and the flying time is very short; it can virtually be considered that during the process of maneuvering and flying, the missile's tangential velocity at every point on the arc AC is v, and that the angle formed by the tangent at every point on arc AC with the straight line AO is very small. Using $v_\perp$ and $v_\parallel$ to represent the vertical and the horizontal speed components of v, and t_0 to show the flight time of the missile from A to its landing point C, we have:

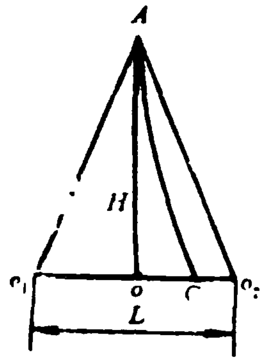

Fig. 1. Missile flight triangle.

$$H=\int_0^{t_0} v_\perp(t)dt=\int_0^{t_0} v\cos q\,dt=\frac{1}{2}\mathrm{ctg}\frac{\theta_c}{2} \tag{17}$$

$$|OC| =\int_0^{t_0} v_\parallel dt =\int_0^{t_0} v\sin q\,dt \tag{18}$$

$$q\approx\frac{1}{2}\eta g t^2/vt=\eta g t/2v \tag{19}$$

Calculation gives us:

$$|OC_2| =\frac{L}{2}+\frac{2v^2}{\eta g}\left(\cos\frac{\eta g}{2v}t_0-1\right) \tag{20}$$

Using the formula on L to find the partial derivative we obtain:

$$\frac{\partial |OC_2|}{\partial L}=\frac{1}{2}+\frac{2v^2}{\eta g}\sin\frac{\eta g}{2v_0}t_0\frac{\partial t_0}{\partial L} \tag{21}$$

After substituting (19) into (17) and solving for the integral, corresponding to L, we derive $\partial t_0/\partial L$; substituting in formula (21), we make it equivalent to zero and solve for t_0, and then substitute into (20). Further, we make $|OC_2|$ equivalent to the missile's destructive radius *R*, and so can obtain the optimal distance between the two points as

$$L_{opt}\geqslant 2\left[R+\frac{2v^2}{\eta g}\left(1-\cos\frac{\theta_c}{2}\right)\right] \tag{22}$$

In actual engineering practice, it is also possible to use another method to find the distance *L* between the two points. When the divergent angle of the missile head with respect to the two points is the missile head antenna split angle θ_c, and the missile turns toward tracking a target, assume that the time the angle tracking system requires for adjustment is t_z; the distance between the two sources can be determined as follows:

$$L\geqslant 2\left(vt_z\mathrm{tg}\frac{\theta_c}{2}+R\right) \tag{23}$$

Here, R is the missile's destructive radius.

D. When two point source interference is used in the direction of the main radar lobe, the following formula will show the oscillation amplitude at the composite field where the target is located:

$$A=E_{m}\sqrt{1+\beta^{2}+2\beta\cos\left[\Omega_{b}t+\frac{2\pi}{\lambda}\left(r_{1}-r_{2}\right)-\varphi\right]} \qquad (24)$$

In the formula, is the ratio of the field strength of the two points; Ω_b is the difference between the frequencies of the two sources, r_1-r_2 is the difference in distance between the two sources and the target location. In the case of coherent two-point sources, $\Omega_b=0$. It can be seen from formula (24) that, in the case of incoherent two-point sources, the composite field amplitude has a low frequency modulation. In the case of coherent two-point sources, the composite field amplitude rises or falls in accordance with the target motion; a multiple lobe phenomenon arises in the space. All this can affect the observation of the target and angle tracking. For this reason, it is most appropriate to use two-point source interference in the direction of radar parasitic and rear lobes. If it is desired to use two-point source interference along the main lobe direction, in order to avoid affecting the observation of the target and the tracking, one solution is to use a coded signal, giving the radar and the interference source signal a very small mutual correlation, and a relatively good autocorrelation pulse pressure. It is also possible to use frequency spectrum central receiver technology in the radar that is to be protected to suppress the incoherent source signal.

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